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W O Criminale

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Washington
Seattle WA 98195

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The research addressed a class of exact solutions for the Navier-Stokes equations which are valid for basic flows with shear, can be time-dependent and non parallel, fully three-dimensional, and offer closed-form functions for the perturbation field. Linearized initial-value problems can be completely solved by this method. Problems which were studied in the course of the research included the elliptic vortex, linear initial value problems, and exact solutions to the Navier Stokes equations.

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FINAL TECHNICAL REPORT
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PRINCIPAL INVESTIGATOR: W.O. Criminale
Department of Applied Mathematics, FS-20
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195
(206) 543-9506

INTRODUCTION

The basis for the research conducted under these auspices rests primarily with the presentation of Craik and Criminale (1986) (A.D.D. Craik and W.O. Criminale, PROC. ROY. SOC. London, A 406, 13-26, 1986) that deals with a class of exact solutions for the Navier-Stokes equations. These solutions are novel and valid for basic flows with shear, can be time-dependent and non parallel, fully three-dimensional, and offer closed-form functions for the perturbation field. Moreover, linearized initial-value problems can be completely solved when the approach is adapted to such inquiries (cf. W.O. Criminale and P.G. Drazin, STUDIES IN APPLIED MATHEMATICS, 83, NO. 2, 123-157, 1990). As a result, a wide range of heretofore unsolved problems can be investigated. For example, fully finite amplitude perturbations dealing with breakdown of elliptical vortices as well as the complete spatial and temporal dynamic history of small perturbations can be ascertained. In addition, the solutions can be used for a Lagrangian representation, thereby forming a means to understand mixing and structure in particular flow fields.

OPERATION

Professor A.D.D. Craik (St. Andrews University, Scotland) collaborated with the Principle Investigator for the full period of this grant. Exchange visits were made (1989, 1990, 1991) as well as extensive correspondence.

PROBLEMS

(1) Elliptical Vortex. By use of the exact solutions, elliptical vortices were examined for stability and breakdown. Analytically, this problem could be reduced to solving an ordinary differential equation of the Mathieu form but with three parameters. Numerical solutions were found necessary and this task was successfully completed at the University of St. Andrews with a manuscript accepted for publication (A.D. Craik and H.R. Allen, The stability of three-dimensional time-periodic flows with spatially uniform strain rates, Journal of Fluid Mechanics, accepted for publication, 1991).

(2) Linear Initial-Value Problems. Under this heading, three particular problems have been explored with each one having a central area of importance. First, a general class of solutions for an infinite mean shear flow was probed for both causal and vortical driving. Besides being able to fully understand the effects of three-dimensionality, this approach has the remarkable output that provides solutions that can be considered fundamental for flows without vorticity. Thus, the results are valid for treating a wide variety of initial-value, boundary value problems. A manuscript will shortly be submitted for publication. (See Publication 2)

The second group of problems deals with understanding perturbations near boundaries where viscous corrections must be made. Easthope and Criminale (See Publication 1) demonstrated explicitly that an initial-value problem can be correctly solved within this environment and found that the transient period was dominated by the continuous spectrum, depends on the scale of the disturbances, and even suggests that the streaky patterns now known to exist in boundary layers can be explained by this model. Finally, three-dimensionality is deemed of major significance.

Because of the manner that the analytical method was able to circumvent the trauma of the Airy equation, it was thought that a general treatise should be made for perturbations near boundaries. This work is in preparation (See Publication 4) and will be explicit with answering such questions as the importance of time scales (advective and diffusive), the role of the critical layer, and it is even anticipated that a contribution to the topic of boundary layer receptivity can be made.

The last group of problems combines traditional knowledge of stability theory that uses a normal mode approach and the correct general formulation that includes the continuous spectrum. On the one hand, the transition from the near field and early time periods to the asymptotic status and far field is of salient interest. Since the solutions using this method allows for explicit closed forms, this history can be made equally as explicit and this is being done (See Publication 5). On the other hand, but in the same vein, the explicit solutions can be used to shift the observation of the problem from an Eulerian to a Lagrangian frame of reference. When this is done, a set of three coupled nonlinear ordinary differential equations becomes the center of the analysis. And, as can be imagined, all of the expectations of such a system to bifurcations and chaotic behavior can be expected. This work is in progress and will direct its attention to structure, mixing, and vorticity (See Publication 6).

(3) Exact Solutions for Navier-Stokes. Criminale and Drazin have been able to generalize the original formulation of Craik and Criminale and, although the work is not thought to be one of new research, it is believed that it represents an assessment and better understanding and therefore will be submitted as a review paper (See Publication 3).

In all of the above work, it is suggested that much of the results are offered for the first time and, indeed, it is the first time the initial transit period has ever been demonstrated in any fashion. Utility of the work may still have many more applications - such as the mixing layer, for example.

PUBLICATIONS, REPORTS

(1) An alternative approach to disturbances in boundary layers, P.F. Easthope and W.O. Criminale, THE LUMLEY SYMPOSIUM: RECENT DEVELOPMENTS IN TURBULENCE, Springer-Verlag, 1991

(2) Fundamental solutions in perturbed shear flows, W.O. Criminale and F.I.P. Smith, to be submitted

(3) On a class of exact solutions for Navier-Stokes equations, W.O. Criminale and P.G. Drazin, in preparation

(4) Effects of viscosity on perturbations in boundary layers, W.O. Criminale, P.G. Drazin, and P.F. Easthope, in preparation

(5) The time evolvement of disturbances in shear flows, W.O. Criminale and B. Long, in preparation

(6) Particle paths, vorticity, and mixing in Couette flow, W.O. Criminale and B. Long, in preparation